

Precision measurements, extra quark-lepton generations and 50 GeV neutrinos

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Abstract

The existence of extra chiral generations with all fermions heavier than m_Z is strongly disfavored by the precision electroweak data. However the data still allow a few extra generations if the neutral leptons have masses close to 50 GeV. Such heavy neutrino can be searched in the reaction $e^+e^- \rightarrow N\bar{N}\gamma$. Existence of 50 GeV neutrinos makes standard model Higgs boson invisible.

1 Introduction

The Standard Model (SM) constitutes three generations of quarks and leptons. Nobody knows any deep reason for the number of generation to be equal three. There are no theoretical arguments against addition of extra sequential generations into SM. So it would be interesting to understand whether such generations are allowed by existing experimental data.

The direct experimental searches have found no trace of any extra quarks or leptons. The lower bounds on the masses of unobserved generations are collected in the PDG tables [1]. The value of the bounds are of the order of 100 GeV - they are fixed by the energy of the acting accelerators.

There is also indirect way to study new generations with arbitrary heavy masses. To do that one has to study radiative corrections and compare theoretical predictions with precision experimental data [2] - [7]. Indeed new particles are produced as the virtual states in the propagation of the gauge bosons. These new loop corrections into self-energies of propagators ("oblique" corrections) slightly change the predictions of the SM for low-energy physical observables. If the accuracy of the experimental data is

better than the value of these new corrections one can exclude or discover new generations comparing theoretical predictions with precision measurements.

Consider this possibility in more details. All set of nearly 20 observables¹ that have been measured at LEP I, SLAC, Tevatron and in νN experiments (including the axial coupling g_A , the ratio $R = g_V/g_A$, and the ratio m_W/m_Z) in the framework of the SM can be determined in terms of three functions V_i ($i = A, R, m$) [8]:

$$m_W/m_Z = c + \frac{3c}{32\pi s^2(c^2 - s^2)} \bar{\alpha} V_m \quad . \quad (1)$$

$$g_{Al} = -\frac{1}{2} - \frac{3}{64\pi s^2 c^2} \bar{\alpha} V_A \quad , \quad (2)$$

$$R \equiv g_{Vl}/g_{Al} = 1 - 4s^2 + \frac{3}{4\pi(c^2 - s^2)} \bar{\alpha} V_R \quad . \quad (3)$$

The contribution of the new generations modifies the SM value of the function V_i by δV_i . It is important that interaction of gauge bosons with new particles is universal, i.e. the gauge coupling constants are the same for any generations. So the loop corrections to the gauge boson propagators can't be made arbitrary small, they are unambiguously fixed by gauge couplings and by the masses of virtual particles. The second important observation is that the matter in the SM is the chiral one, i.e. left-handed leptons and quarks belong to $SU(2)$ doublets while their right-handed companions are $SU(2)$ singlets. In this case heavy flavors do not decouple from the low-energy physics even for very large masses, i.e. radiative corrections remain finite when the masses of virtual particles go to infinity.

For example in the case of one extra generation $(UD)_L$, $(NE)_L$, U_R , D_R , N_R , E_R with fully degenerate doublets ($m_U = m_D = m_N = m_E$) and ($m_U \gg m_Z$) one obtains "finite" corrections:

$$\delta V_A = 0 \quad , \quad \delta V_R = -\frac{8}{9} \quad , \quad \delta V_m = -\frac{16}{9} s^2 \quad . \quad (4)$$

In the opposite case when $SU(2)$ is strongly violated ($m_U \gg m_D$ or $m_U \ll m_D$) all corrections δV_i are enhanced by the ratio of mass:

$$\delta V_i = \frac{|m_U^2 - m_D^2|}{m_Z^2} + \frac{1}{3} \frac{|m_N^2 - m_E^2|}{m_Z^2} \quad . \quad (5)$$

¹ Decay $Z \rightarrow b\bar{b}$ needs special consideration.

Thus extra heavy generations can be excluded if these additional contributions δV_i exceed the discrepancy between the SM fit and precision experimental data or can be "discovered" if they improve the fit.

In this way it was found [1] - [6] that the existence of extra chiral generations with all fermions heavier than M_Z is strongly disfavored by the precision electroweak data (see section 2). The message of this talk is that there is a small region in the parameter space where new generations could still exist. Namely electroweak data are fitted nicely even by a few extra generations, if one allows neutral leptons to have masses close to 50 GeV [7] (see section 3). Such neutrinos are still allowed by existing experimental data. In section 4 we will consider the ways to detect heavy 50 GeV neutrinos.

During the discussions at this conference it was noted by Valery Khoze [10] that if heavy neutrinos do exist the decay rate of the Standard Model Higgs boson into the pair of heavy neutrino would be about two order of magnitude higher than into $b\bar{b}$, i.e. the predominant decay mode of Higgs boson would be invisible.

2 Heavy generations and LEPTOP fit to experimental data

We compare theoretical predictions for extra generations with experimental data [9] with the help of the code LEPTOP [11]. In what follows we will assume that the mixing of the new generations with the three old ones is small. Thus new fermions contribute only into oblique corrections (vector boson self energies).

Heavy neutrinos need special consideration. There are two ways to make neutrino massive. One can introduce right-handed neutrals N_R and supply new "neutrinos" with Dirac masses analogously to the case of charged leptons and quarks. Another way is to construct Majorana heavy neutrino. In this paper we do not consider that possibility, our neutral lepton is a heavy Dirac particle.

We perform the four parameter $(m_t, m_H, \alpha_s, \bar{\alpha})$ fit to 18 experimental observables. The fitted parameters together with the values of the predicted observables and their pulls from the experimental data are given in the Table 1. The conclusion of the fit is quite evident: **Standard Model fit of experimental data statistically is very good.**

Table 1: LEPTOP fit of the precision observables.

Observ.	Exper. data	LEPTOP fit	Pull
Γ_Z [GeV]	2.4952(23)	2.4964(16)	-0.5
σ_h [nb]	41.541(37)	41.479(15)	1.7
R_l	20.767(25)	20.739(18)	1.1
A_{FB}^l	0.0171(10)	0.0164(3)	0.7
A_τ	0.1439(42)	0.1480(13)	-1.0
A_e	0.1498(48)	0.1480(13)	0.4
R_b	0.2165(7)	0.2157(1)	1.2
R_c	0.1709(34)	0.1723(1)	-0.4
A_{FB}^b	0.0990(20)	0.1038(9)	-2.4
A_{FB}^c	0.0689(35)	0.0742(7)	-1.5
s_l^2 (Q_{FB})	0.2321(10)	0.2314(2)	0.7
s_l^2 (A_{LR})	0.2310(3)	0.2314(2)	-1.5
A_b	0.911(25)	0.9349(1)	-1.0
A_c	0.630(26)	0.6683(6)	-1.5
m_W [GeV]	80.434(37)	80.397(23)	1.0
s_W^2 (νN)	0.2255(21)	0.2231(2)	1.1
m_t [GeV]	174.3(5.1)	174.0(4.2)	0.1
m_H [GeV]		55^{+45}_{-26}	
$\hat{\alpha}_s$		0.1183(27)	
$\bar{\alpha}^{-1}$	128.88(9)	128.85(9)	0.3
χ^2/n_{dof}		21.4/14	

There is only one cloud on the blue sky - the experimental value of the forward-backward asymmetry in the Z decay into the pair of b-quarks A_{FB}^b shows a hint for disagreement with Standard Model.²

Now we compare theoretical predictions for the case of the presence of extra generations. The procedure is the following:

First we take $m_D = 130$ GeV – the lowest value allowed for the new quark mass from Tevatron search [12] and take $m_U \gtrsim m_D$. As for the leptons from the extra generations, their masses are independent parameters. To simplify

² With new BES and Novosibirsk data the accuracy of $\bar{\alpha}^{-1}$ has to be improved in the nearest future. For value $\bar{\alpha}^{-1} = 128.945(60)$ from ref.[16] LEPTOP fit gives slightly higher prediction for the higgs mass $m_H = 78^{+53}_{-32}$ GeV, $m_t = 174.1(4.5)$ GeV, $\alpha_s = 0.1182(27)$, $\bar{\alpha}^{-1} = 128.927(58)$ and $\chi^2/n_{dof} = 21.1/14$.

the analyzes we start with $m_N = m_U$, $m_E = m_D$. Any value of higgs mass above 113GeV is allowed in our fits, however χ^2 appears to be minimal for $m_H = 113\text{ GeV}$.

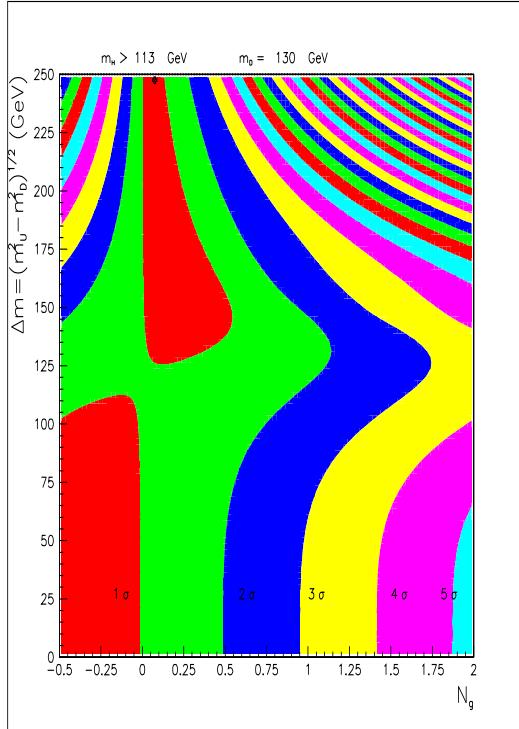


Figure 1: Constraints on the number of extra generations N_g and the mass difference in the extra generations Δm . The lowest allowed value $m_D = 130\text{ GeV}$ from Tevatron search was used and $m_E = m_D$, $m_N = m_U$ was assumed.

In Figure 1 the excluded domains in coordinates $(N_g, \Delta m)$ are shown (here $\Delta m = (m_U^2 - m_D^2)^{1/2}$ and the number of extra generations N_g is considered as a continuous parameter). Minimum of χ^2 corresponds to $N_g = 0.1$. We see that one extra generation corresponds to 2σ approximately.

We checked that similar bounds are valid for the general choice of heavy masses of leptons and quarks. In particular we found that for $m_N = m_D = 130\text{ GeV}$ and $m_E = m_U$ one extra generation is excluded at 1.5σ level, while for $m_E = m_U = 130\text{ GeV}$ and $m_N = m_D$ the limits are even stronger than in Fig.1.

The conclusion of this section is the following:

Extra generations are excluded by the electroweak precision data, if all extra fermions are heavy: $m \gtrsim m_Z$.

3 "Light" heavy neutrino

Lower bounds on charged flavors m_E , m_U , m_D are approximately 100 GeV-130 GeV. However neutral lepton N can be considerably lighter.

From LEP II searches of the decays $N \rightarrow lW^*$, where W^* is virtual while l is e , μ or τ , it follows that $m_N > 70 - 80$ GeV for the mixing angle of the 4th generation with three known generations larger than 10^{-6} [13]. The quasi-stable neutral lepton N with mixing angle less than 10^{-6} is allowed even for $m_N < 70$ GeV. In this case neutrino N escapes detection from this LEPII search. The direct DELPHI bound from the measurement of the Z -boson width is much weaker: $m_N > 45$ GeV [14]

We consider the case when new heavy neutrino has Dirac mass in the region of $m_Z/2$. For particles with masses of the order of $m_Z/2$ oblique corrections drastically differ from what we have for masses $\gtrsim m_Z$. In this case the Z boson state and $N\bar{N}$ state are practically degenerate and even small mixing term can produce large change for eigenfunctions. In other words renormalization of Z -boson wave function due to $N\bar{N}$ intermediate state has to be large.

It happens that large wave function renormalization due to "light" neutrino N and contributions from "genuine heavy" U, D and E to V_i have opposite sign. For very narrow region of the mass we have rather good compensation. Thus corrections to SM formulas δV_i are small and we have the kind of heavy generation conspiracy.

As an example we take $m_U = 220$ GeV, $m_D = 200$ GeV, $m_E = 100$ GeV and draw exclusion plot in coordinates (m_N, N_g) , see Fig.2. From this plot it is clear that for the case of fourth generation with $m_N \approx 50$ GeV description of the data is not worse than for the Standard Model and that even two new generations with $m_{N_1} \approx m_{N_2} \approx 50$ GeV are allowed within 1.5σ .

The conclusion of this section is the following:

If the neutral lepton N has mass around 50 GeV the new generations are not excluded by the electroweak precision data.

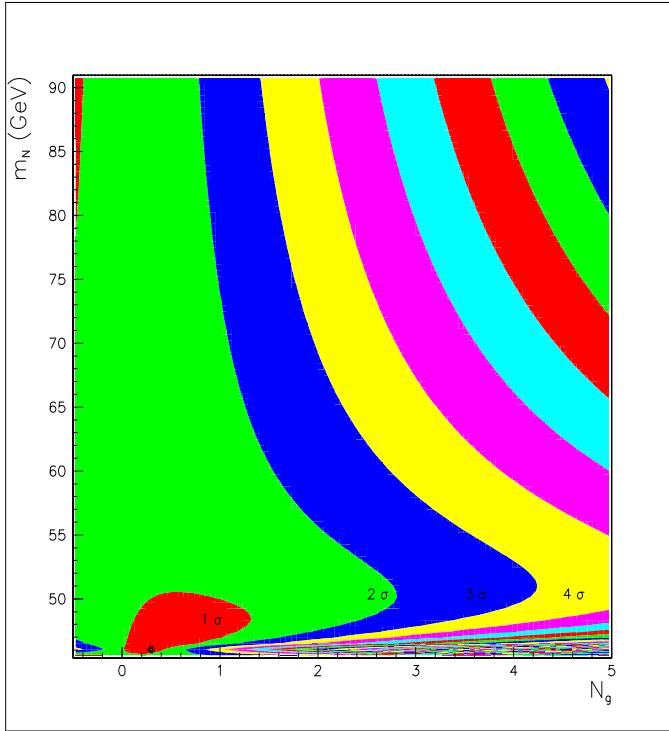


Figure 2: Constraints on the number of extra generations N_g and the mass of the neutral heavy lepton m_N . The values $m_U = 220$ GeV, $m_D = 200$ GeV, $M_E = 100$ GeV were used

4 The direct search of the heavy neutrino

The direct search of the heavy neutrino is possible in e^+e^- -annihilation. As was proposed a long time ago [15], the cross section of e^+e^- -annihilation into an invisible final state can be inferred from observation of initial state bremsstrahlung, i.e from e^+e^- -annihilation into a pair of heavy neutrinos with the emission of initial state bremsstrahlung photon

$$e^+e^- \rightarrow \gamma + N\bar{N} \quad (6)$$

The main background is the production of the pairs of conventional neutrinos with initial state bremsstrahlung photon

$$e^+e^- \rightarrow \gamma + \nu_i\bar{\nu}_i \quad (7)$$

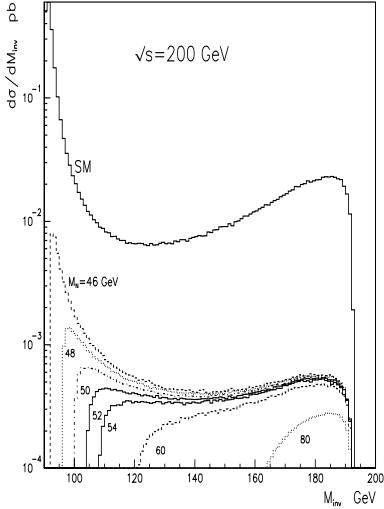


Figure 3: $d\sigma/dM_{inv}$ (in pb) for Standard Model and for the different values of m_N .

where $i = e, \mu, \tau$. These background neutrinos are produced in decays of real and virtual Z . In case of $\nu_e \bar{\nu}_e$, two mechanisms contribute, through s -channel Z boson and from t -channel exchange of W boson. We calculated the signal and background distributions and rates [17] using CompHEP [18] computer code.

In Fig.3 the distribution on “invisible” mass M_{inv} (invariant mass of the neutrino pair) is represented for SM background and the $N\bar{N}$ signal for $\sqrt{s} = 200$ GeV and different values of N masses, $M_N = 46 - 100$ GeV. Here we applied kinematical cuts on the photon polar angle and transverse momentum, $|\cos \vartheta_\gamma| < 0.95$ and $p_T^\gamma > 0.0375\sqrt{s}$, being the ALEPH selection criteria [19]. The photon detection efficiency 74% is assumed. For highest significance of the $N\bar{N}$ signal, evaluated as $N_S/\sqrt{N_B}$, one should include whole interval on M_{inv} allowed kinematically, so we applied $M_{inv} > 2m_N$ cut.

On Fig.4 the signal significances are represented as a function of m_N . One can derive that only the analysis based on combined data from all four experiments both from 1997-1999 runs ($\sqrt{s} = 182 - 202$ GeV) and from the final run, in total ~ 2600 pb $^{-1}$, can exclude at 95% CL the interval of N

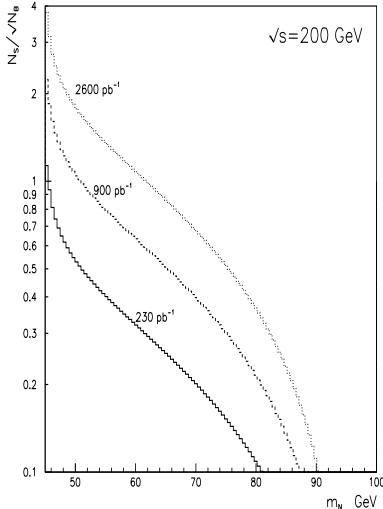


Figure 4: $N\bar{N}$ signal significances at LEP-2 at different statistics as function of the neutrino mass.

mass up to ~ 50 GeV.

Another possibility is to search for 50 GeV neutrino at the future TESLA $e^+ - e^-$ electron-positron linear collider. The increase in energy leads to the decrease both of the signal and the background, but it is compensated by the proposed increase of luminosity of $300 \text{ fb}^{-1}/\text{year}$ [20]. Further advantage of the linear collider is the possibility to use polarized beams. This is important in suppressing the cross section of $e^+e^- \rightarrow \nu_e\bar{\nu}_e\gamma$ as this reaction goes mainly through the t -channel exchange of the W boson. However, even without exploiting the beam polarization the advantage of TESLA in the total number of events is extremely important. Thus, Standard Model is expected to give approximately 0.3 million single photon events for $M_{inv} > 100$ GeV while the number of 50 GeV neutrino pairs would be about 4000.

Although the signal over background ratio is still small (2.3-0.5% for $m_N = 45 - 100$ GeV correspondingly) the significance of the signal is excellent, higher than 5 standard deviations for $m_N < 60$ GeV.

The conclusions of this section are the following:

Combined data from four LEP II experiments can exclude at 95% CL neutrino with $M_N < 50$.

Future collider TESLA in one year run can exclude at 95% CL the whole region of m_N or can discover neutrino within 5 standard deviations with $m_N < 60$ GeV.

5 Conclusions

The existence of extra chiral generations with all fermions heavier than m_Z is disfavored by the precision electroweak data. A few extra generations with "light" neutral leptons, i.e. with mass M_N close to 50 GeV, are not excluded yet by existing data. Such heavy neutrino can be searched in the reaction $e^+e^- \rightarrow N\bar{N}\gamma$.

After this talk Valera Khoze made simple and important observation, that 50 GeV neutrino makes Standard Model Higgs boson invisible, that require a special strategy for its search [10].

6 Acknowledgements

I am grateful to the organizers of La Thuile conference, particularly to Mario Greco, for their outstanding hospitality and for a very pleasurable and thought provoking conference.

References

- [1] J.Erler, P.Langacker, Review of Particle Physics. The European Physical Journal **C3** (2000) P. 103, Chapter 10.6.
- [2] N.Evans, Phys. Lett. **B340** (1994) 81.
- [3] P.Bamert and C.P.Burgess, Z. Phys. **C66** (1995) 495.
- [4] V.A.Novikov, L.B.Okun, A.N.Rozanov et al., Mod. Phys. Lett. **A10** (1995) 1915; Erratum - ibid. **A11** (1996) 687.
- [5] A. Masiero et al., Phys.Lett.**B355** (1995) 329.
- [6] T.Inami et al.,Mod.Phys.Lett.**A10** (1995) 1471.T.Inami et al.,Mod.Phys.Lett.**A10** (1995) 1471.

- [7] M.Maltoni,V.A.Novikov, L.B.Okun et al., Phys. Lett. **B340** (2000) 81.
- [8] V.A.Novikov, L.B.Okun, M.I.Vysotsky, Nucl.Phys. **B 397** (1993) 35.
- [9] LEP Electroweak Working Group, LEPEWWG/2001-01.
- [10] V.Khoze, hep-ph/0105069 .
- [11] V.Novikov et al., Preprint ITEP 19-95; Preprint CPPM -1-95; http://cppm.in2p3.fr./leptop/intro_leptop.html
- [12] Review of Particle Physics. The European Physical Journal C **3** (2000) Number 1-4.
- [13] K.Ackerstaff et al., (OPAL), Europ. Phys. J. **C1** (1998) 45.
- [14] P.Ferrari et al., DELPHI 98-55 PHYS 780.
- [15] A.Dolgov, L.Okun and V.Zakharov, Nucl.Phys. **B41** (1972) 197.
- [16] Bolek Pietrzyk, in Proceedings ICHEP2000 Osaka conference.
- [17] V. Ilyin, M. Maltoni, V. Novikov et al., hep-ph/0006324.
- [18] A.Pukhov et al, CompHEP user's manual v.3.3, Preprint INP MSU 98-41/542 (1998); hep-ph/9908288.
- [19] ALEPH Coll., Phys. Lett. **B429** (1998) 201.
- [20] www.desy.de/njwalker/ecfa-desy-wg4/ parameter_list.html